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The effect of carbon tax to reduce CO_2 emissions : A case of Japanese households

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Abstract

The Kyoto Protocol came into effect on February 16, 2005. As of January 2006, the number of signatory countries was over 158, and these countries had already started developing strategies to curb CO_2 emissions. Japan has ratified and started some projects. However, Japan is still in a state of uncertain to achieve the Kyoto target. Recently, an introduction of the carbon tax is discussed for ensuring the achievement. This paper examines how the impact of carbon tax to reduce CO_2 emissions from households side. The cabon tax has three effects : (i) an incentive effect, (ii) a subsidy for introduction of energy-efficient equipment, and (iii) an announcement effect. Our simulation resutls conclude that the incentive effect can reduce CO_2 emissions about 21.26 Mt, but that is not enough. What is worse is that the second effect highly depends on the rebound effect and the adoption rate of energy-efficient equipments. Therefore, to achieve the Kyoto target, lowering the rebound effect and accelerating the diffusion of equipments are needed. The announcement effect has a possibility to drive them.

Keywords : Carbon tax, energy conservation policy, CO_2, Japanese houholds and rebound effect.

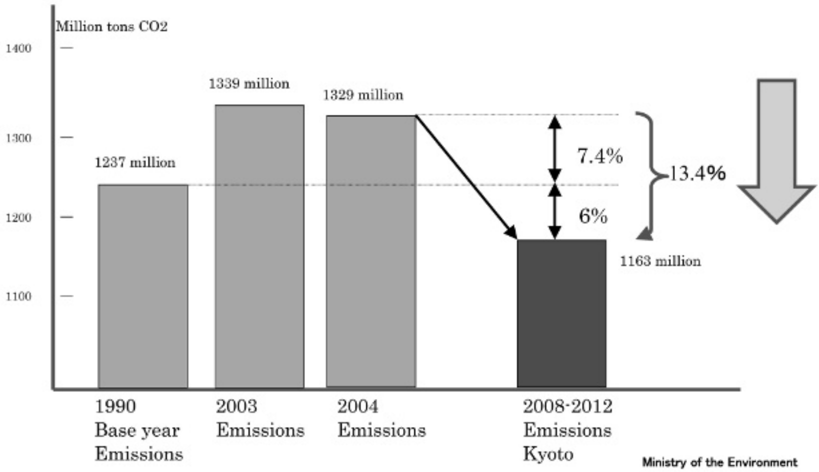
1 Introduction

The Kyoto Protocol came into effect on February 16, 2005. Japan has also ratified the Kyoto Protocol and has been required to reduce Green House Gas (hereafter, GHG) emissions 6% below base year (1990) emissions level during a first commitment periods (2008-2012). Figure 1 shows a transition of the amount of GHG emissions (equivalent in CO_2) in Japan. From this figure, because the base year emissions level and target emissions level are 123.7 Mt and 116.3 Mt respectively, the amount of emission cuts in Japan are 74.0 Mt. However, the GHG emissions has increased about 7.4% since 1990, and in 2004, total emissions has been 132.9 Mt. As a result, Japan have been obligated to reduce GHG emissions about 166.0 Mt-CO_2.

Attaining the goal of Kyoto Protocol, Japan has started some projects based on the "Climate Change Policy Programme". According to this programme, Japan chooses as far as possible to do without the Kyoto mechanism, such as an emission trading, a clean development mechanizm (CDM), and a joint implementation (JI) and tries to choose the methods to reduce the CO_2 emissions at home. For examples, in a supply-side, a development and a diffusion of new energy, a fuel switching, a forest absorption, a diffusion of nuclear power, etc. In the demand-side, a development and a diffusion of energy saving equipments, an environment education, etc. However, because of a fiscal shortage, the backwardness of a development and a diffusion of such new technology, it is expected that the achieved the Kyoto target is difficult given the present circumstances.

For ensuring the goal of the Kyoto Protocol, Ministry of the environment proposed an introduction of "the carbon" tax system recently. This system imposes a tax on the consumption of fossil fuel as energy in proportion to the carbon contents of the fuel. The carbon tax has been planed separately from the

Figure 1. Green House Gas (GHG) emissions in Japan



conventional tax systems of energy, such as a petroleum & coal tax and a promotion of power resources development tax.[1] Table 1 shows tax amounts on each fuel which were proposed by 2005's carbon tax scheme. The object of taxation are 10 kinds of fuel, such as (i) electricity, (ii) city gas, (iii) LPG, (iv) heating oil, (v) petrol, (vi) coal, (vii) heavy oil, (viii) natural gas, (ix) diesel oil, and (x) jet fuel. Table E indicates tax amounts of other contries which already introduced carbon tax system. Compared with them, the tax rate is set low level.[2] This is attributed to the fact that the whole concept of Japanese carbon tax is to complement the activities of other emissions-reduction strategies. Japanese government is

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1) These are tax systems that impose on the fossil fuel and energy. Both tax systems were amended in 2002 for the global warming. In the petroleum & coal tax system, the taxation for a coal were added and increase in taxation for a natural gas and a LPG were maked up. On the other hands, in the promotion of power resources development tax system, a reduction in taxes was taken place for the electricity.

2) Japanese tax amounts are similar to these of Netherlands.

Table 1.　Carbon tax（yen/measure）

	Electricity	City Gas	LPG	Heating Oil	Petrol
Measure	(kWh)	(m^3)	(kg)	(l)	(l)
	0.25	1.38	1.96	0.82	1.52

	Coal	Heavy Oil	Natural Gas	Diesel Oil	Jet Fuel
Measure	(kg)	(l)	(kg)	(l)	(l)
	1.58	1.80	1.76	1.72	1.61

Data source : Ministry of the Environment

planning to use the tax revenue for compensating the budget of other strategies in “Climate Change Policy Programme”.[3)]

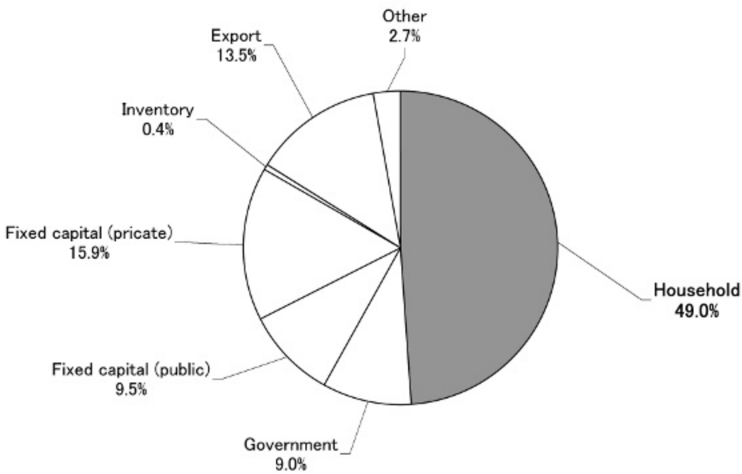
The carbon tax has three aims : the first aim is a reduction of carbon dioxide emission by incentive effects. This is the original theoretical aim of carbon tax. Tax is passed along to costs, and by income effect and substitution effect accompanied by it, use amount of CO_2 emission origin can be reduced so that the whole CO_2 emission can also be reduced. The second aim is a financial procurement of subsidy for introduction of save-energy equipment and technology. While increasing investment in save-energy equipment because of the increase of energy cost subsidy is provided for introduction of technology which contributes to prevention of global warming. Through both sides of measures, introduction of technology of good energy efficiency is promoted, and by raising the energy efficiency as a whole, CO_2 emission will be reduced. The third aim is an announcement effects, and this effect is considered to be important. Through the act of each people to pay taxes in daily life, the existence of global warming and the

3) According to the proposed scheme of the carbon tax, the tax revenue are planning to use for（i）development and maintenance of timber,（ii）accelerating the diffusion of new energy,（iii）accelerating the diffusion of energy-efficient equipment, etc.

need of reduction of CO_2 emission can be recognized by the people, and it will accelerate the effort of decreasing CO_2 emissions by them.

Figure 2 indicates the share of induced CO_2 emissions from each final demand in 1995. The induced CO_2 emissions means the amount of CO_2 emissions which also include the emissions from a production and a distribution process of each goods. According to this figure, the share of induced CO_2 eimssions from households are 49%. That is, about the half volume of Japanese induced CO_2 emissions is generated from households. From this fact, it can be expected that a review of consumption behavior will affect the large impact to the reduction of CO_2 emissions. That is, if the carbon tax is imposed on households, through above three effects, households will try to reduce CO_2 emissions. Then, combined with the amount of emissions reduction in the supply side, it is expected that large volume of CO_2 emissions is declined. This paper investigate how the impact of the

Figure 2. Induced CO_2 emissions from final demand in japan (1995)



Data source : Yoshioka et al (2003)

carbon tax to reduce CO_2 emissions from the households side. We focus on the three effects of the carbon tax : (i) an incentive effect, (ii) a subsidy effect, and (iii) an announcement effect, respectively.

This paper is organized as follows. Section 2 conducts an empirical analysis of the Japanese households demand model. In section 3, with the estimated parameter of the demand model, we conduct a simulation analysis of the carbon tax. We examine two simulation analyses for the incentive effect and the subsidy effect, and based on these results, we examine the scenario analysis for the announcement effect. Section 4 presents concluding remarks.

2 Empirical Analysis

2.1 The Data

The data used in this study pertains to the expenditure of Japanese households on nondurable commodities. The data comprises time series monthly data from January 1990 to December 1999. Following Brannlund et al. (2005), the data pertaining to consumption are classified into the following four main categories : (i) food, (ii) fuel and light, (iii) transportation, and (iv) others. Figure 3 illustrates the detailed composition of each of these commodities. Further, each main category comprises some sub commodities. First, food expenditures are

Figure 3. Between and within budgeting model

********************************** **Main Group** **********************************

FOOD	FUEL & LIGHT	TRANSPORT	OTHER

********************************** **Sub Group** **********************************

Food Eating-out	Electricity Gas Heating oil	Car transport Public transport Other transport	Clothing Medical care Recreation Communication Miscellaneous

classified into two sub commodities : food (including beverages) and eating out. Second, fuel and light expenditures are classified into electricity, gas (propane and city gas), and heating oil. Third, transportation expenditures can be grouped as car transportation (gasoline and maintenance), public transportation (train and buses), and other transportations (taxis and airplanes). Finally, the category of others comprises clothing, medical care, recreation, communication, and miscellaneous.[4)]

All these commodities yield CO_2 emissions in their production and consumption processes. Hence, the data pertaining to their expenditure are associated with CO_2 emissions in the following manner :

$$CO_{2,i} = \theta_i x_i$$

where x_i represents the per capita expenditure on goods i ; θ_i represents the CO_2 emission factor that measures the amount of CO_2 emissions generated by the production, distribution and consumption processes of goods i .

The data pertaining to the expenditure and price for each of the commodities were obtained from the Family Income and Expenditure survey. The standard physical unit of CO_2 emission (i. e., θ) has been derived from Nakamura and Otoma (2004).[5)]

Table 2 presents the CO_2 emissions and the average percentage shares for the expenditure on each of the goods per month. According to this table, the total expenditure and CO_2 emissions on a monthly basis are 310,492 yen and 1,232.56

4) This paper deals with only non-durable goods. However, even if we consider the durable goods, the amount of additional CO_2 emissions from them are only 14.9 kg, and these are only 1.2% in the total emissions. Therefore, it is to be expected that the error of empirical analysis may be small.

5) Nakamura and Otoma (2004) calculated the CO_2 emissions factor (kg-CO_2/yen) from Nansai et al (2002) a database of an environmental burden basic unit that was derived using the input-output table for 400 categories. This factor can take into account both direct and indirect CO_2 emissions in the production process. Table A shows their CO_2emission factors for the expenditure on each of the goods.

Table 2. Expenditure and CO_2 emissions per month (Average (1990 : 1-1999 : 12))

	Total expenditure (yen)	Total expenditure share (%)	CO_2 emission ($kg\text{-}CO_2$)	CO_2 emission share (%)
Food	72,155	23.24	171.97	14.0
Eating-out	14,803	4.77	28.22	2.3
Electricity	8,592	2.77	148.07	12.0
Gas	5,691	1.83	80.22	6.5
Heating oil	1,231	0.40	76.71	6.2
Car trans	13,286	4.28	350.76	28.5
Public trans	5,096	1.64	28.40	2.3
Other trans	958	0.31	10.47	0.8
Clothing	22,037	7.10	40.40	3.3
Medical care	9,202	2.96	16.87	1.4
Recreation	30,658	9.87	67.45	5.5
Communication	7,271	2.34	8.00	0.6
Miscellaneous	119,512	38.49	205.02	16.6
All	310,492	100.0	1232.5	100.0

$kg\text{-}CO_2$, respectively. We can infer that car transport-with an expenditure share of 4.28%-accounts for the largest proportion of CO_2 emissions : 28.5%. Even if the expenditure share of electricity is only approximately 2.77%, it accounts for the fourth largest share of CO_2 emissions : 12.0%. Moreover, with regard to expenditure and CO_2 emissions, we can infer that food consumption accounts for a relatively large share ; it contributes to 23.24% of the total expenditure and 14.0% of the total CO_2 emissions. Further, the recreation and miscellaneous categories also contribute to a relatively large share of the expenditure and CO_2 emissions.

2.2 Econometric model of the Household Demand

Following Brannlund et al.(2005), we apply the Almost Ideal Demand System (hereafter, AIDS) model suggested by Deaton and Muellbauer (1980) and extend it to the two-stage AIDS model proposed by Edgerton et al. (1996). Following this, we can specify the AIDS model for the r^{th} group, as follows :[6)]

$$w_{(r),t} = \alpha_{(r)} + \beta_{(r)} ln\left(\frac{X_t}{P_t}\right) + \sum_{s=1}^{4} \gamma_{(r)(s)} lnp_{s,t} + \epsilon_{(r),t}, \quad (1)$$
$$lnP_t = \sum_{s=1}^{4} w_{(r),t}\, lnp_{(s),t}, \qquad \varepsilon_{(r),t} \sim N(0, \Sigma), \qquad r = 1,\ldots, 4$$

where $w_{(r),t}$ represents the expenditure share of the r^{th} group at time t. We denote the total expenditure by X_t and the group price by $p_{(r),t}$, where t represents the time dimension.[7)] P_t is referred to as the *Stone's* price index. This model provides the first-order approximation to an arbitrary demand system and satisfies the perfect aggregation conditions for all consumers.

Following Green and Alston (1990), in which each of the estimated parameters are provided, the price and income elasticities[8)] can be calculated in the following manner :

$$\eta_{(r)(s)} = -\delta_{rs} + \frac{\gamma_{rs}}{w_r} - \frac{\beta_r}{w_r}\left[\sum_k w_k\, lnp_k\, (\eta_{(k)(s)} + \delta_{kj})\right] \quad (2)$$

$$\eta^I_{(r)} = 1 + \frac{\beta_r}{w_r}\left[1 - \sum_k w_k\, lnp_k\, (\eta^I_{(k)} - 1)\right], \quad (3)$$

where $\eta_{(r)(s)}$ represents the price elasticity and δ_{rs} represents the Kronecker product that is equal to 1 with $r = s$, and zero otherwise. $\eta^I_{(r)}$ represents the income elasticity.

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6) This AIDS model can be applied for each subgroup. Therefore, there are five equations that need to be estimated.

7) We can also test the restrictions of the demand model, such as adding-up, homogeneity, and symmetry. With respect to the notation used for the main groups, these restrictions can be written as follows :

Adding up : $\sum_s^4 \alpha_s = 1,\ \sum_s^4 \beta_s = 0,\ \sum_s^4 \gamma_{sr} = 0,$
Homogeneity : $\sum_r^4 \gamma_{sr} = 0,$
Symmetry : $\gamma_{sr} = \gamma_{rs}, \forall r,\ s$.

8) In the present analysis, we use the expenditure data of Japanese households. Hereafter, we refer to income as total expenditure. In most of the demand analyses, total expenditure is used instead of income.

In order to calculate the total income elasticity for the i^{th} goods within the r^{th} category, we represent the subgroup income elasticity for the i^{th} goods within the r^{th} category as $\eta^{I}_{(r),\, i}$, and the income elasticity for the main group of the r^{th} category of goods as $\eta^{I}_{(r)}$. Therefore, the total income elasticity η^{I}_{i} is :

$$\eta^{I}_{i} = \eta^{I}_{(r)} \times \eta^{I}_{(r),\, i} \tag{4}$$

In a similar manner, we represent the within-group price elasticity between the i^{th} and j^{th} goods within the r^{th} category as $\eta_{(r)ij}$; the group price elasticity is represented as $\eta_{(r)(s)}$, and the total price elasticity as η_{ij},[9] which can be written as follows :

$$\eta_{ij} = \delta_{rs}\eta_{(r),\, ij} + \eta^{I}_{(r),\, i} w_{s,\, j} \left(\delta_{rs} + \eta_{(r)(s)}\right) \tag{5}$$

In this study, we use the Bayesian estimation method-namely the Markov Chain Monte Carlo (hereafter, MCMC) method-for estimating the parameters of the AIDS model. Recent advances in computer simulations have simplified the implementation of Bayesian analysis to diverse contexts (for example, see Gelman et al. (2003)). The following are some advantages of adopting the Bayesian method : (i) using the Deviance Information Criteria (DIC), we can compare with other functional forms easily, when the dependent variables used in different models are different or transformation of each other (Xial et al. (2006)). (ii) The estimated elasticity of each commodity can be tested using a 95% credible interval.[10] (iii) The 95% credible interval of the rebound effect can also be

9) It should be noted that the within-group price elasticity assumes that the group expenditure remains unchanged despite the price change, while the total price elasticity allows for relevant changes in group expenditure.

10) We are usually interested in price and income elasticities of equation (2), (3), (4) and (5), not estimated parameters of α_i, β_i and γ_i in equation (1). Most of the past studies, however, obtain only the point estimates of these elasticities and do not show the confidence intervals of these elasticities.

obtained and its significance can be tested.

Using the same regressors for each equation, the AIDS model is formed as a Seemingly Unrelated Regressions Model (hereafter, SUR). Chib and Greenberg (1995) suggested the adoption of an MCMC sampling method, such as the Gibbs sampler, for the SUR model. Xial et al.(2006) applied the same Bayesian estimation method for the AIDS model, and in an example analysis on American households, tested four types of functional forms pertaining to the residential energy demand models.

The Bayesian estimation method can be described as follows : (i) The prior distributions of $\theta=\{\alpha, \beta, \gamma\}$ and Σ of equation (1),[11] were determined. (ii) The posterior distributions for each of the parameters were derived by combining the prior distribution with the likelihood function that can be obtained from the assumption of ϵ. (iii) A random number from these posterior distributions was generated by the Gibbs sampling method. (iv) Finally, based on these random numbers, the Bayes estimator and credible interval for θ and Σ of equation (1) can be estimated (See Xial et al.(2006) for details). In this paper, we set 11000 iterations and using a "burn-in" of 1000 iterations.

2.3 Estimation results

Due to the adding-up restriction, one of the equations in each of the AIDS models gets omitted at the estimation stage. Data pertaining to each of the expenditures and prices might develop a seasonality ; therefore, we used X12

11) We assume a normal and inverted Wishart distribution as follows :

$$\theta \sim N(\mathbf{b},\ B), \qquad \Sigma \sim inuW(v_0,\ \Lambda),$$

where $B=5\times10^6\times I_{N*k}$, $v_0=10$ and $\Lambda=5\times500\times I_N$ respectively (I, N and k denote an identity matrix, the number of observations, and a parameter, respectively). We use SUR parameters that are estimated by the OLS method for parameter vector $\mathbf{b}$.

standards to adjust for it. Most of the resulting estimated parameters were significantly different from zero. Further, we test the homogeneity and symmetry restrictions, the results for which are illustrated in Tables B and C. The results indicate that in general, these restrictions can be rejected. The only exception is the subgroup of food, where the restrictions of homogeneity and symmetry cannot be rejected.

We should take into account other functional forms, such as log-linear and translog specifications. Based on the method of Xial et al.(2006), we tested them using a Bayesian model selection criterion, the Deviance Information Criteria (DIC). Models with smaller values of DIC are preferred to ones with larger DIC values.[12] Table 3 shows these values for each model. It is clear from this table that the AIDS specification outperforms the log-linear and translog specifications for all commodity groups. Furthermore, the DICs for the translog specification are similar to the AIDS. These results are consistent with Xial et al.(2006). From this point of view, it is appropriate to adapt the AIDS specification for our analysis.

Table 4 presents both, the estimated within-group and between-group prices and income elasticities. Several evidences support this demand model. First, most of the own price elasticities have a negative value and are significantly different from zero.[13] Second, these elasticities are consistent with those obtained by other studies

Table 3. Values of DIC for log-linear, translog, and AIDS models

(DIC)

	Group	Food	Fuel & Light	Trans	Other
Log-Linear	4,615.7	2,089.1	2,910.1	2,935.3	6,449.1
Trans-Log	4,414.1	1,799.9	2,771.7	2,878.7	6,288.8
AIDS	4,410.9	1,779.7	2,771.0	2,878.1	6,213.4

12) For a detailed discussion, see Xial et al.(2006).

Table 4. Estimated Price Elasticities and Income Elasticities

	Own Price Elasticity	Income Elasticity	Total Own Price Elasticity	Total Income Elasticity
(Main Group)				
Food	−0.50	0.68		
Fuel and Light	−0.64	0.98		
Transport	−1.15	1.02		
Other	−0.98	1.15		
(Food)				
Food	−0.79	1.06	−0.36	0.73
Eating-out	0.17	0.68	0.23	0.46
(Fuel and Light)				
Electricity	−1.12	1.21	−0.88	1.19
Gas	−0.63	0.54	−0.55	0.54
Heating Oil	−0.25	1.67	−0.20	1.65
(Transport)				
Car trans	−0.49	1.18	−0.61	1.21
Public trans	−0.11	0.49	−0.13	0.50
Other trans	−3.07	1.18	−3.08	1.20
(Other)				
Clothing	−0.97	1.47	−0.97	1.68
Medical care	−0.34	0.50	−0.34	0.57
Recreation	−1.11	0.55	−1.10	0.63
Communication	−1.09	0.16	−1.08	0.18
Miscellaneous	−0.86	1.12	−0.84	1.28

that have used Japanese data. Hashimoto (2004) estimated the AIDS model for 10 commodities (food, housing, fuel & light, furniture, clothing, medicine, transport, education, recreation, and others) from 1963 to 2001. Further, using annual data between 1966 and 1996, Ogura and Ohtani (2006) estimated the own-price elasticity for five commodities (food, housing, fuel & light, clothing, and others). Table D presents the own-price and income elasticities for each of these goods.

A majority of our results are consistent with the estimation results of Hashimoto

13) In Bayesian inference, if a 95% credible interval does not include zero, we consider the parameter to be significant.

(2004) and Ogura and Ohtani (2006)[14] Therefore, we can conclude, within reason, that these empirical results for the demand model will be valid for analyzing household behavior.

3 Simulation Analysis

Based on the results obtained from the previous section, here, we examine a simulation study. Following the proposal of Japanese environmental tax, we evaluate the effect of it to reduce CO_2 emissions. At the same time, we also consider the policy mix with the energy saving strategy, because the tax revenue is planed to use for accelerating an improvement in energy efficiency. First of all, we introduce the simulation method. And after that, we adapt this method for analyzing both an environmental tax and an energy saving strategies.

3.1 Simulation study of the carbon tax

In this subsection, based on the proposed rate of the environmental tax by Ministry of the Environment on October 2005, the effectiveness of this tax system to reduce CO_2 emissions will be investigated. The simulation method of Brannlund et al. (2005) is extended as follows.

Let us assume ϕ_i to be the percentage increase (%) in the environmental tax for energy goods i.[15] Then, the new price level for goods i can be represented as follows :

$$p_i^1 = p_i^0 (100 + \phi_i)/100 \tag{6}$$

where p_i^0 and p_i^1 prepresent the price levels before and after the taxation,

14) There exist some differences between their estimation results and ours. These can be attributed to the following two reasons, (i) the differences in the estimated terms and (ii) the differences across the annual and monthly data.

respectively. The new *Stone's* price index for the commodities belonging to the r^{th} category is written as follows :

$$lnP^1_{(r)} = \Sigma_{i \in r}\, w_{(r),\,i}\, lnp^1_i, \tag{7}$$

where $w_{(r),\,i}$ represents the initial share of expenditure on the i^{th} good in the category r. Therefore, the *Stone's* price index for the entire category can be presented as follows :

$$lnP^1 = \Sigma_r\, w_{(r)} lnp^1_{(r)}, \tag{8}$$

where $w_{(r)}$ represents the share of total expenditures on goods belonging to the category r, prior to the tax levy.

Replacing the *Stone's* price index of the AIDS model by new ones-(7) and (8)) the first-stage budgeting process provides a new allocation across the commodity groups. Therefore, the AIDS model for the rth category can be presented in the following manner :

$$w^1_{(r)} = \hat{\alpha}_{(r)} + \hat{\beta}_{(r)} ln\left(\frac{X^0}{P^1}\right) + \Sigma_s\, \hat{\gamma}_{(r)(s)} lnp^1_{(s)} + \hat{\epsilon}^0_{(r)}, \tag{9}$$

where $\hat{\alpha}$, $\hat{\beta}$, and $\hat{\gamma}$ represent the parameters estimated in the previous section. X^0 represents the initial total per capita expenditures and $\hat{\epsilon}^0$ represents the estimated residual expenditures that are assumed to remain constant across the simulation

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15) In this simulation analysis, assuming a 20% improvement in the energy efficiency, we model a (20−X)% decline in the cost of energy as a (20−X)% decline in its price. Since the cost of gasoline accounts for 40% of the costs of car transport, the price of car transport is reduced by [(20−X)×0.4]%. Owing to data limitations, we can not observe the production functions for public and other forms of transportation ; therefore, the share of energy goods for public and other forms of transportation are assumed to be 20% and 25%, respectively. This indicates a price reduction of [(20−X)×0.2]% and [(20−X)×0.25]% price reduction, respectively (these assumptions follow the principle of Brannlund et al.(2005)).

analysis.

From equation (9), we can calculate the new expenditure share for each of the commodities; hence, the new per capita expenditure for the r^{th} category can be represented as $X^1_{(r)} = w^1_{(r)} X^0 (r = 1,\dots, 4)$. Substituting this new per capita expenditure $X^1_{(r)}$ into the AIDS demand system for the r^{th} category, we can calculate the new expenditure share for the i^{th} goods belonging to the r^{th} category in the following manner:

$$w^1_{(r),\ i} = \hat{\alpha}_{(r),\ i} + \hat{\beta}_{(r),\ i} ln\left(\frac{X^1_{(r)}}{P^1_{(r)}}\right) + \sum_j \hat{\gamma}_{(r),\ j} lnp_j^1 + \hat{\epsilon}^0_{(r)}, \tag{10}$$

Brannlund et al. (2005) used the expenditure share for each of the goods and categories-such as $w^1_{(r),\ i}$ and $w^1_{(r)}$, for the following analysis. However, there is no guarantee that they will converge with only a single trial. This is because, after we get the new shares of expenditure, each *Stone* price index of equations (7) and (8) will also change, and might again affect the expenditure share for each of the goods. Therefore, it is necessary to iterate the sequence of this simulation in parts-from equations (7) to (10), -until each of the values pertaining to the expenditure share converge. If there is only one-iteration, the simulation results have bias (see Mizobuchi (2006) in detail). We assume that the asterisk (＊) denotes the convergent value. Given a converged expenditure and a converged expenditure share of i^{th} good on group r, the change in expenditure can be defined as follows:

$$\Delta \tilde{X}_i = w^*_{(r),\ i} X^*_{(r)} - w_{(r),\ i} X^0_{(r)}. \tag{11}$$

Therefore, by multiplying θ, we can calculate the change in CO_2 emissions with a taxation, which is presented in the following manner:

$$\Delta E_i = \sum_i \theta_i \Delta \tilde{X}_i, \qquad i = 1,\dots, n(r),\ r = 1,\dots, 4, \tag{12}$$

where the changes in CO_2 emissions-ΔE_r-in the above equation are equal to ΔE^1 of equation ⒀ for the r^{th} category.

－*Results*－

Table 6 shows the simulation results. First column represents the results of the case which the environmental tax is imposed, and the variations of the CO_2 emissions from each goods are shown. From these results, if the environmental tax is imposed, the demand for fuel & light and transport goods will decrease, and CO_2 emissions are also declined. Especially, the decrease of the demand for car transport and electricity are relatively larger than other goods. On the other hands, the reduction of the demand for gas, public trans (bus and train) and other trans (taxi and air-plane) are relatively small. Furthermore, if we focus on the goods which are not imposed the environmental tax, the demand of these goods slightly increase. Therefore, the amount of CO_2 emissions reduction from the goods of taxation will be slightly offset by these goods of no taxation. Totally, the amount of CO_2 emissions reduction from a household is 40 kg per month (481 kg per year).

Based on the number of households in 2005 (it is about 49062 thousand), table 7 shows total reduction of the induced CO_2 emissions from households sector, when the environmental tax is imposed. From table 7, total reduction effect has been 21.26 ($MtCO_2$) per year.[16)]

According to the Kyoto Protocol, Japan has to lower the CO_2 emissions about 166 million ton from the emissions level of 2004. Here, according to the "Climate

16) The CO_2 emissions factors of this paper are calculated based on the input-output table on 1995. Through some revisions of the energy saving low, it is completely natural to think that there were improvements in energy efficiency in the production and distribution process until 2005. In this paper, we suppose that there were at least 10% technological improvements in these process. In addition, this assumed value is based on "Environmental Volunteer Active Plan" of Nippon Kendanren.

Change Policy Programme", Japan reduce the CO_2 emissions as the following strategies ; (i) 47.67 (Mt-CO_2) by the use of Sinks, (ii) 34.00 (Mt-CO_2) by a new energy, (iii) 18.00 (Mt-CO_2) by a fuel switching and a nuclear promotion, (iv) 19.79 (Mt-CO_2) by a Kyoto mechanism, and (v) 15.00 (Mt-CO_2) by a improvement in energy efficiency. Therefore, subtracting them from the target reduction (166 million ton) , the remaining target emissions reduction by households is about 31.54 (Mt-CO_2).

Compared with the emissions reduction from the environmental tax, households sector has to reduce 10.24 (Mt-CO_2) incrementally. Then, we take into account the additional effect which the tax revenue will be used for developing and expanding use of energy saving products, such as TV, air-conditioner, lighting, etc. In the next subsection, we will discuss the effect of energy savign strategy on households.

3.2 Simulation study of the energy saving policy

―*Rebound effect*―

In this subsection, the amount of CO_2 emissions reduction will be calculated by the simulation when the households use the energy saving products. Here, there is one issue to be considered before this analysis.

Essentially, if an improvement in energy efficiency occur, the energy consumption will decrease, and it also lower the CO_2 emissions. However, the effect of energy savings may be offset by a behavioral response. Improvement in energy efficiency in turn leads to a reduction in the cost of energy servies per unit, which results in increasing the demand for energy services. Therefore, the anticipated energy savings from the new technology are canceled out in response to the cost reduction. Earlier studies have referred to this effect as the "rebound effect."

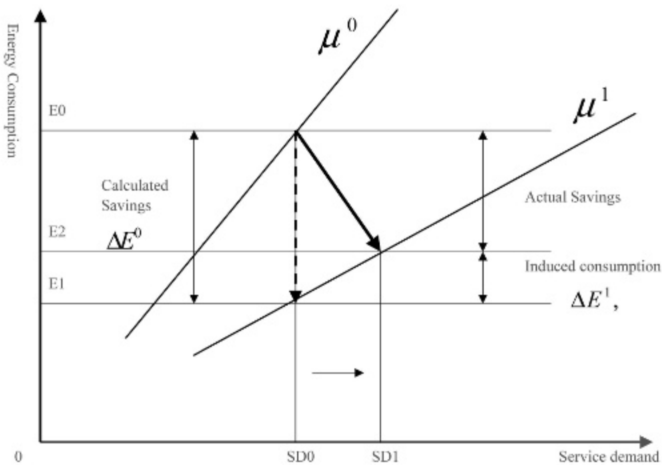
Figure 4 helps to illustrate the rebound effect. The vertical axis indicates energy consumption and the horizontal axis indicates energy service demand. The line μ denotes the efficiency level of energy service. An improvement in energy efficiency from μ^0 to μ^1, assuming that the service level remains constant, would reduce energy consumption from E_0 to E_1. However, as described previously, in real life, consumers might increase their energy service demand from SD_0 to SD_1 which implies an energy consumption of E_2.

Let us consider $\Delta E^0(E_0 - E_1)$ as a calculated energy saving when there is an improvement in energy efficiency and $\Delta E^1(E_2 - E_1)$ as an increase in the energy consumption due to a reduction in the cost of energy services. Thus, the rebound effect can be defined as follows :

$$\text{Revound Effect}(\%) = \left|\frac{\Delta E^1}{\Delta E^0}\right| \times 100 \tag{13}$$

Mizobuchi (2006) and Mizobuchi (2007) estimates the rebound effect of

Figure 4. Rebound Effect



Japanese households, and obtaines empirical evidence of it. Therefore, if we evaluate the energy saving strategy, we have to take account the rebound effect For such occasions, assuming an exogenous improvement in energy efficiency, we investigate the magnitude of the rebound effect.

―*Estimation of the rebound effect*―

A new energy conservation technology is accompanied by a decrease in the cost of energy services per unit. However, it is difficult to directly measure the extent of this cost reduction; hence, following Brannlund et al. (2005), we assume that an improvement in energy efficiency is modeled in the form of a price reduction. In other words if there is an improvement in the energy efficiency for i goods, we decrease the prices of these goods instead of reducing their costs. We assume a 20% improvement in the energy efficiency for "fuel and light" (electricity, gas, and oil) and "transportation" (car transport, public transport, and other transport), and other goods, such as hybrid cars, air-conditioners, TVs, and lighting.

The analysis of Brannlund et al. (2005) does not take into consideration the replacement cost of the new energy-saving products. However, consumers first need to purchase these products in order to use them, and these new energy saving products are usually more expensive than the inefficient ones. Therefore, in order to calculate the rebound effect correctly, it is natural that we should take into account these replacement costs. As mentioned previously, Henly et al. (1988) explained this problem from a theoretical perspective; however, most of the earlier empirical analyses on the rebound effect did not take into consideration the effects of replacement costs. Therefore, these studies might have overestimated the magnitude of the rebound effect.

Mizobuchi (2006) extends the method of Branndlund et al. (2005) with taking into account the replacement costs. In this paper, following Mizobuchi (2006), we assume a 20% improvement in energy efficiency ; however, we need to take into consideration the replacement costs associated with this improvement X(X<20). In other words, the actual net reduction in the cost is only (20−X)%. Moreover, we have taken into consideration the energy required for the production of these energy saving products.[17)]

The same simulation method in the pervious section can be used in this analysis, and we can calculate the changes in CO_2 emissions. From simulation results, we can derive the magnitude of the rebound effect based on the equation (13). However, the formulation of equation (13) is changed as follow :

$$p_i^1 = p_i^0\,(100-(\phi_i - X))/100$$

We consider four types of replacement costs X-0, 5, 10 and 15. Therefore, the cases of cost reduction will also be of four types-20%, 15%, 10% and 5%.[18)]

―*Results*―

Table 5 presents the simulation results. Based on the size of replacement costs in the second column, the first column presents the rate of cost reduction that ranges between 20% and 5%. The third column shows the rate of change of CO_2 emissions when energy service costs decline. The fourth column presents the rate

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17) From the production and transportation processes of the new energy saving products, CO_2 emissions will be generated. Therefore, we allocate the replacement costs (X) for purchasing these energy saving products, and CO_2 emissions from them are added to the amount of the calculated saving (ΔE^0).

18) In this simulation analysis, assuming a 20% improvement in the energy efficiency, we model a (20−X)% decline in the cost of energy as a (20−X)% decline in its price. Since the cost of gasoline accounts for 40% of the costs of car transport, the price of car transport is reduced by [(20−X)×0.4]%. Owing to data limitations, we can not observe the production functions for public and other forms of transportation ; therefore, the share of energy goods for public and other forms of transportation are assumed to be 20% and 25%, respectively. This indicates a price reduction of [(20−X)×0.2]% and [(20−X)×0.25]% price reduction, respectively (these assumptions follow the principle of Brannlund et al.(2005)).

Table 5. The Estimated Rebound Effects (in the case of 20% improvement in energy efficiency)

(1)	(2)	(3)	(4)	(5)
Cost Saving (20−X) (%)	Replacement Cost X	Rebound ΔE^1 (%)	Technological saving ΔE^0 (%)	Rebound Effect (%)
20	0	8.988 [7.943, 10.074]	−7.360	122.108 [107.917, 136.867]
15	5	5.898 [5.171, 6.649]	−7.234	81.527 [71.489, 91.914]
10	10	2.917 [2.463, 3.384]	−7.107	41.044 [34.649, 47.608]
5	15	0.039 [−0.187, 0.266]	−6.981	0.556 [−2.676, 3.806]

1. The range in the parentheses represent the 95 percent credible interval of the estimated parameter.
2. ΔE^0 = (potential CO_2 emissions reduction by improvement in energy efficiency) + (additional CO_2 emissions from the production and distribution process of the replacement products)

of reduction of the potential CO_2 emissions (%) when accompanied by a 20% improvement in energy efficiency. This value includes the amount of CO_2 emissions that were generated from the production and distribution process of the replacement products. Finally, the rightmost column presents the magnitude of the rebound effect.

As can be seen in the first row of table 5, the rebound effect becomes approximately 122% with a 20% reduction in the energy service costs (i. e., no replacement costs), which is significantly different from zero.

This implies that the 20% exogenous improvement in energy efficiency will not reduce CO_2 emissions. On the contrary, the amount of CO_2 emissions will be greater than before. This effect is a special case of the rebound effect. In the literature, this effect is called as the "backfire effect". This estimated size of the rebound effect is larger than that obtained by Washida (2006); Washida focused on all the Japanese sectors-industrial, transportation, household, etc. As estimated in this study, the rebound effect lies between 35.21% and 70.27%.[19] However, he also does not consider replacement costs.

It appears to be rather impractical that there are no replacement costs in the case of new energy saving products. As mentioned previously, our simulation analysis can take into consideration the replacement cost in order to measure the rebound effect. Further, Table 5 presents several examples of varying replacement costs. From this table, we can observe that the magnitude of the rebound effect decreases with an increase in the replacement cost. For example, when replacement costs increase from 0 to 5, the magnitude of the rebound effect decreases from 122% to 82%. And when replacement costs increase from 5 to 10, the magnitude of the rebound effect decreases from 82% to 41%. Our empirical evidences support the fact that previous empirical studies-based on Khazzoom's (1980) formulation-might overestimate the rebound effect. From a practical viewpoint, as a result of replacement costs, it becomes unrealistic to predict that a 20% reduction in energy services cost will be generated when there is a 20% improvement in energy efficiency. Therefore, it is more practical to consider those examples in which there is less than 20% decline in energy services cost, such as the cases in which there is a cost reduction of up to 15%, 10%, or 5%. We also find that the rebound effect will not be significant[20] for the highest replacement costs in our simulation (i. e., X=15). That is, the anticipated energy saving by a technological improvement will be attained completely if the cost savings are very small.

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19) However, Washida's analysis has one limitation. From empirical studies, we realize that the magnitude of the rebound effect significantly depends on the magnitude of elasticities, such as those arising from the production and demand functions. However, the elasticities of his model were not the estimated ones based on his data (See Washida (2006)).

20) That is, the 95% credible interval of the estimated rebound effect (−2.676, 3.806) includes zero.

3.3 Policy mix with the carbon tax and energy saving

Table 6 presents the chnges in CO_2 emissions of each goods when the exogenous 20% improvement in energy efficiency occur. In the previous subsection, we calculated the magnitude of the rebound effect with each size of replacement costs (hereafter, we call them as a case 1, 2 and 3). From second to fourth column of table 6 shows the results of each case.[21)]

Table 6. Estimated changes of CO_2 emissions (kg-CO_2) per household

	Carbon Tax	Energy Saving 1 (RE=82%)	Energy Saving 2 (RE=41%)	Energy Saving 3 (no RE)
〈Food〉				
Food	2.239	−4.370	−2.136	−0.054
Eating-out	0.230	−0.466	−0.229	−0.009
〈Fuel & Light〉				
Electricity	−9.332	−10.020	−13.521	−25.512
Gas	−2.001	−13.970	−15.504	−16.722
Heating oil	−4.537	−31.075	−24.099	−21.862
〈Transport〉				
Car trans	−26.481	29.285	1.582	−24.721
Public trans	−1.167	2.761	1.072	−0.506
Other trans	−0.798	1.602	0.629	−0.283
〈Other〉				
Clothing	0.306	−0.803	−0.443	−0.096
Medical care	0.043	−0.125	−0.070	−0.017
Recrearion	0.195	−0.534	−0.295	−0.067
Communication	0.007	−0.022	−0.012	−0.003
Miscellaneous	1.182	−3.148	−1.741	−0.391
Food	2.469	−4.836	−2.365	−0.063
Heating	−15.870	−55.065	−53.124	−64.096
Transport	−28.447	33.648	3.283	−25.510
Other	1.732	−4.632	−2.561	−0.574
〈Total〉				
Monthly	−40.116	−30.885	−54.767	−90.243
annual	−481.392	−370.062	−657.204	−1082.916

1. Energy saving 1 is a simulation which considers the 25% replacement costs.
2. Energy saving 2 is a simulation which considers the 50% replacement costs.
3. Energy saving 2 is a simulation which considers the 75% replacement costs.

21) The case of no replacement costs causes a "back-fire effect". Therefore, we exclude this case in our analysis.

In the case 1, most reduction effect from energy saving products will be cancelled out by the large rebound effect, and total CO_2 emissions reduction per households becomes about 31 kg/month (370 kg/year). This value much belows the estimation results of the environmental tax. In the case 2, because of the relatively-small size of the rebound effect, anticipated energy savings from a technological progress will not be canceled out so much. The reduction of CO_2 emissions per households becomes about 55 kg/month (657 kg/year). This result is about 1.8 times of the case 1. In the case 3, there is no rebound effect because replacement costs are very large. Thereby, the potential CO_2 emissions reduction will no canceled out, and the total emissions reduction per households becomes about 90 kg/month (1,083 kg/year). This result is about triple size of the case1and about 2.25 times of the result of the environmental tax.

As in the case of an environmental tax, based on the number of households in 2005, the total induced CO_2 emissions reduction is calculated in each case. These results are shown in second, third and fourth column in table 7. There is one

Table 7. Reduced CO_2 emissions ($Mt\text{-}CO_2$) by the emvironmental strategies

	(1)	(2)	(3)	(4)
Adoption rate	Carbon Tax	Energy Saving 1 (RE=82%)	Energy Saving 2 (RE=41%)	Energy Saving 3 (no RE)
100%	21.256	16.340	29.019	47.817
40%	−	6.536	11.608	19.127
30%	−	4.902	8.706	14.345
20%	−	3.268	5.804	9.563
10%	−	1.634	2.902	4.782
5%	−	0.917	1.458	2.391

1. Energy saving 1 : the case considers the 25% replacement costs.
2. Energy saving 2 : the case considers the 50% replacement costs.
3. Energy saving 3 : the case considers the 75% replacement costs.

caution, the environmental tax laid on all energy, such as electricity, gas, heating oil, petrol, etc, that households consume, as long as households use home appliances, heat pump water heater, passenger vehicle, etc. However, in the case of energy saving strategy, we can not obtain the saving effect unless households purchase these energy efficient products. That is, the size of the effect of energy saving strategy depends upon an adoption rate. Table 7 shows the estimated CO_2 emissions reduction considering the five types of the adoption rate of products (such as 5%, 10%, 20%, 30% and 40%) for each case.

From table 7, in the smallest replacement costs case (i. e., the case 1), even if an adoption rate is 40%, the emissions reduction becomes only 6.54 (Mt-CO_2). In this case, although this emissions reduction sums up with that from an environmental tax, total emissions reduction becomes 27.79(Mt-CO_2) which are lower than our target level (31.54(Mt-CO_2)).

Let us move on to the case 2. The third column of table 7 shows this result. We can figure out that if the adoption rate is 40%, total induced CO_2 emissions reduction is 11.61(Mt), and sum up with that of an envirnmental tax becomes 32.86(Mt-CO_2). Therefore, we can achieve the goal of emissions reduction. However, if the adoption rate is lower than 40%, the amount of emissions reduction will not reach the goal.

The extreme right column of table 7 shows the results of the case 3. This case does not have the rebound effect, thereby, the largest emissions reduction can be attained. From the table, if the adoption rate is 30% or 40%, the emissions reductions become 14.35(Mt-CO_2) and 19.13(Mt-CO_2), respectively, and sums up with the effect of an environmental tax are 35.60(Mt-CO_2) and 40.38(Mt-CO_2). Needless to say, the goal of emission reduction will be achieved in both cases.

For simplicity, if we ignore the adoption rate, taking on the scenario of the case 3 with no rebound effect is a good choice to achieve the Kyoto target.

Moreover, if more than 30% adoption rate is attained, we can reduce extra CO_2 emissions, and these superfluous reductions can be sold as an emission credit to other countries. However, an implementation of this scenario is not easy, because an increase the adoption rate by attaining the goal of emissions reduction is expected to be difficult. It's just conceivable that the large size of the replacement costs interrupts a rise of an adoption rate. Therefore, it's natural to believe that the adoption rates of case 1 and case 2 are higher than that of the case 3, because their replacement costs are smaller than case 3. Given this perspective, it is expected that an order of the adoption rate is case 1, case 2 and case 3 in descending order. From our empirical reuslts, however, even if the 40% adoption rate (i. e., highest rate in our simulation) can be attained in case1, the goal can not be achieved. Furthermore, in the case 2 and the case 3 which is to be expected lower adoption rate, it is impossible to achieve the goal with such a 10% or a 20% adoption rates. Therefore, even if the energy saving technology improves at a rapid rate, it is hard to achieve the goal of the emissions reduction, unless these energy saving products become widely used in households.

It is probable that the carbon tax can accelarate a diffusion of using energy saving products. It is a "Announcement Effects". Through the act of each people to pay taxes in daily life, the existence of global warming and the need of reduction of CO_2 emission can be recognized by the people.[22] It can be hardly said that widespread use of energy saving equipment go on as planned.[23] From this paper, there is a trade-off between the rebound effect and adoption rate. In ordre to increase the adoption rate, if the Japanese government gives more subsidies to energy-efficient appliances than inefficient ones, it is possible that the impact of the

22) See the report of Ministry of the Environment for a detailed discussion.
23) "Climate Change Policy Programme" saying that Japan needs an explosive growth of energy saving equipment as soon as possible.

rebound effect is amplified. Therefore, for increasing the adoption rate with a low rebound effect, we need an introduction of the carbon tax as rapidly as possible.

4 Conclusion

This paper has examined how the impact of the carbon tax which proposed by Ministry of the Environment in 2005 on Japanese households to reduce CO_2 emissions. Our analysis has measured total emissions reduction effect of the policy mix with the carbon tax and energy saving strategy. In doing so, the adoption rate of energy-efficient appliances and the rebound effect have been taken into account in the simulation analysis. From the empirical analaysis, it has become clear that the high adoption rate is needed to achieve the Kyoto target.

Japanese energy saving technology is a top-level in the world. The two oil crises of the 1970s were turning points which saw Japan achieve considerable success in energy conservation. This achievement is especially in an industrial sector. However, in a household sector, the continued pursuit of comfort and convenience by them increased energy consumption. In the former half of the 1990 s, the direction of energy saving strategy started to shift from the industrial sector to the household sector. Furthermore, with the problem of the global warming, the energy saving strategy resulted in accelerating in all sectors more than before. Attaining the Kyoto target, Japanese government takes on some strategies other than energy saving strategy, such as a development and spread of new energy, the Kyoto mechanism, a fuel switching, a nuclear promotion, sinks by a forest, etc. However, even if sum up with the amount of the emission reduction from these strategies, there was still uncertainty to achieve the goal. Ministry of the Environment suggested to introduce the environmental tax (carbon tax) in 2005 to make certain of the implementation.

Carbon tax has three ways to reduce CO_2 emissions: (i) reduction of emission by incentive effects (i. e., a direct effect), (ii) introduction of energy-efficient equipment (i. e., an indirect effect), and (iii) announcement effects. This paper has taken into account the first and the second effect, and we have also considered the third effect in the scenario analysis (see table 7 in detail).

Taking into account the induced CO_2 emissions, we have used CO_2 emission factor of Nansai et al (2002) and Nakamura and Otomas (2004) which can consider the amount of CO_2 emissions generated from the production and the distribution process. Our empirical results show that 21.26 (Mt-CO_2) will decrease by the direct effect. Here, even if all strategies in the "Climate Change Policy Programme" achieve a target of the emission reduction, it is necessary to reduce 31.54 (Mt-CO_2) incrementally. Therefore, we can not reduce them by the direct effect alone.

The size of the indirect effect of the carbon tax depends on the rebound effect (its size depends on replacements costs) and the adoption rate. In the case of the highest rebound effect (i. e., replacement costs are very small), unless the adoption rate is more than 65%, we can not attain the target emissions level. In this case, however, large volumes of a government subsidy will be necessity. On the other hands, with no rebound effect (i. e., replacements costs are very large), if the adoption rate is more than 30%, we can achieve the goal of the target emissions level. However, it seems more likely that the more replacement costs large (i. e., there are not any government subsidy), the more the adoption rate low.

This paper concludes that the carbon tax (which includes direct and indirect effects) has a certain level of impact to reduce CO_2 emissions. However, for attaining the goal of the Kyoto protocol certainly, it is essential to accelerate a diffusion of the energy-efficient appliances for households. Energy conservation in Japan has already progressed to a high level, but in the future, it will be essential for every citizen to taken up the effort to achieve further energy savings. The effect of carbon tax (e. g., an announcement effect) may be one of the helpful method to drive them.

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Table A. CO_2 Emission Factor of each Commodity

Group	Sub-Group	CO_2 emission factor kg-CO_2 / 10 thousand yen
Food		
	Food	23.8
	Eating-out	19.1
Fuel & Light		
	Electricity	172.3
	Gas	141.0
	Heating Oil	623.3
Transport		
	Car trans	264.0
	Public trans	55.7
	Other trans	109.2
Other		
	Clothing	18.3
	Medical care	18.3
	Recreation	22.0
	Communicarion	11.0
	Miscellaneous	17.2

1. From Nakamura and Otoma (2004).
2. The CO_2 emissions factor of "Eating-out", "Gas", "Public trans", "Other trans", "Communication" and "Miscellaneous" were calculated by author from Nansai et al (2002).

Table B. Test of Homogeneity

GROUP	FOOD	FUEL & LIGHT	TRANS	OTHER
	[−0.274, −0.091]*	[0.164, −0.351]*	[−0.234, −0.047]*	[−0.098, 0.225]
FOOD	Food	Eating-out		
	[−0.029, 0.074]	[−0.074, 0.029]		
FUEL & LIGHT	Electricity	Gas	Heating Oil	
	[−0.128, −0.087]*	[−0.111, −0.069]*	[0.169, 0.227]*	
TRANS	Car trans	Public trans	Other trans	
	[0.174, 0.234]*	[−0.217, −0.158]*	[−0.058, 0.026]	
OTHER	Clothing	Medical care	Recreation	Communication
	[−0.277, −0.137]*	[0.038, 0.177]*	[−0.149, −0.007]*	[−0.061, 0.080]
	Miscellaneous			
	[0.026, 0.308]*			

The range in the parentheses represent the 95 percent credible interval of the estimated parameter. The homogeneity can be realized in the following case :

$$H_0 : \Sigma_{j=1}^{M} \gamma_{ij} = 0, \qquad i = 1,\ 2, \ldots,\ M.$$

Therefore, we calculate $10,000\,\Sigma_{j=1}^{M}\gamma_{ij}$, and if the credible interval includes zero, the null hypothesis can not be rejected. In this case, the restriction of homogeneity is realized.

Table C.　Test of Symmetry

	FOOD	FUEL & LIGHT	TRANS	OTHER
FUEL & LIGHT	[−0.004, 0.088]*			
TRANS	[0.016, 0.127]*	[−0.396, −0.193]*		
OTHER	[0.019, 0.103]*	[0.163, 0.316]*	[−0.074, 0.058]	
	Food	**Eating-out**		
Eating-out	[−0.029, 0.074]			
	Electricity	**Gas**	**Heating Oil**	
Gas	[0.151, 0.190]*			
Heating Oil	[−0.296, −0.261]*	[0.061, 0.099]*		
	Car trans	**Public trans**	**Other trans**	
Public trans	[0.172, 0.234]*			
Other trans	[−0.040, 0.033]	[−0.020, 0.058]		
	Clothing	**Medical care**	**Recreation**	**Communication**
Medical care	[−0.103, −0.043]*			
Recreation	[−0.290, −0.203]*	[0.050, 0.110]*		
Communication	[−0.030, 0.097]	[−0.037, 0.032]	[−0.066, −0.037]*	
Miscellaneous	[0.057, 0.120]*	[0.014, 0.083]*	[−0.448, −0.301]*	[0.051, 0.123]*

The range in the parentheses represent the 95 percent credible interval of the estimated parameter. The symmetry can be realized in the following case :

$$H_0 : \gamma_{ij} = \gamma_{ji}, \qquad i,\ j = 1,\ 2, \ldots,\ M.$$

Therefore, we calculate $10,000(\hat{\gamma}_{ij} - \hat{\gamma}_{ji})$, and if the credible interval includes zero, the null hypothesis can not be rejected.　In this case, the restriction of symmetry is realized.

Table D. Own Price Elasticities and Income Elasticities（Past Studies）

Hashimoto（2004）					
	food	house	fuel and light	furniture	clothing
Income	0.598	0.083	0.660	1.339	1.309
Price	−0.405	0.611	−0.039	−0.596	−0.206
	medical care	transport	education	recrearion	other
Income	0.960	1.128	0.900	1.450	1.335
Price	−0.949	−0.802	0.914	0.162	−1.222
Ogura and Ohtani（2006）					
	food	house	fuel and light	clothing	others
Income	0.648	1.309	0.749	1.288	1.146
Price	−0.125	−0.227	−0.090	−0.824	−0.420

Table E.　Carbon tax in other countries（yen/measure）

	Eelctricity	City Gas	LPG	Heating Oil	Petrol
	(kWh)	(m^3)	(kg)	(l)	(l)
Finland	0.90	—	—	6.00	5.30
Sweden	—	—	16.10	15.30	12.50
Norway	—	—	—	7.50	15.00
Denmark	2.00	—	5.40	4.80	—
Netherlands	—	—	2.10	1.70	1.60
	1.80	—	10.60	10.50	—
England	0.80	—	1.80	—	—
Japan	0.25	1.38	1.96	0.82	1.52

	Coal	Heavy Oil	Natural Gas	Diesel Oil	Jet Fuel
Measure	(kg)	(l)	(kg)	(l)	(l)
Finland	5.50	7.20	2.30	6.00	6.00
Sweden	13.30	16.20	11.50	15.30	15.30
Norway	7.50	7.50	11.00	7.50	—
Denmark	4.30	5.70	3.90	4.80	4.80
Netherlands	1.50	2.00	1.40	1.70	1.70
	—	—	5.70	10.60	—
England	2.20	—	0.30	—	—
Japan	1.58	1.80	1.76	1.72	1.61

Data source： Ministry of the Environment